Phreatic Eruptions of the Eastern Snake River Plain of Idaho

by

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ABSTRACT

Split Butte and Sand Butte are tuff cones representing phreatomagmatic eruptions. Both buttes are nested, subcircular structures consisting of a tephra ring and an inner lava lake modified by a pit crater. Split Butte lies west of the Wapi lava flow, about 40 kilometers west-northwest of American Falls, and consists of vitric ash that forms a ring 600 meters across. Sand Butte is 30 kilometers southwest of Craters of the Moon National Monument and consists of palagonitized vitric ash and abundant lithic fragments which form a cone 1.2 kilometers across; a deeper level of magma-water interaction at Sand Butte than at Split Butte is suggested by a greater fraction of lithic ejecta and less vesiculation of the juvenile fraction.

INTRODUCTION

Pleistocene volcanism in the Snake River Plain, Idaho, is dominated by basaltic lava flows that were erupted during relatively quiet activity. In some areas, notably in Craters of the Moon National Monument, more explosive activity produced cinder cones. Although rare in the Snake River Plain, even more violent eruptions occurred in several locations where maars were formed.

In this report the geology of two phreatomagmatic structures of the Snake River Plain is discussed in terms of their formational processes. Split Butte is an asymmetric tuff ring that has been deeply eroded. Sand Butte is a symmetrical tuff cone lying astride a north-south tensional fissure. Both buttes were described in Greeley and King (1975); Womer (1977) and Womer and others (1980) discuss grain size analyses of Split Butte tephra.

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SPLIT BUTTE

Split Butte is in the south-central Snake River Plain (Figure 1). It overlies basalt flows of the Snake River Group (undifferentiated) and was encroached from the southeast by a lobe of the Wapi lava flow, which has been dated at 2,270 ± 50 years (Greeley, 1982 this volume) to place a lower boundary on the age of Split Butte. The butte consists of vitric ash that forms a ring 600 meters across (Figures 2 and 3). The ring is assymmetrical, having a greater accumulation on the east, the result of prevailing winds from the west during the eruption. The tephra ring is also slightly elliptical, with its long axis oriented approximately N. 60° E. It is unknown whether ring ellipticity resulted from vent geometry or prevailing winds. Although the eroded ring stands 50 meters above the surrounding plain, an original ash thickness of 80 meters on the east is estimated from the dip of the

Figure 1. LANDSAT image of the central Snake River Plain, Idaho, showing the location of Sand Butte and Split Butte.

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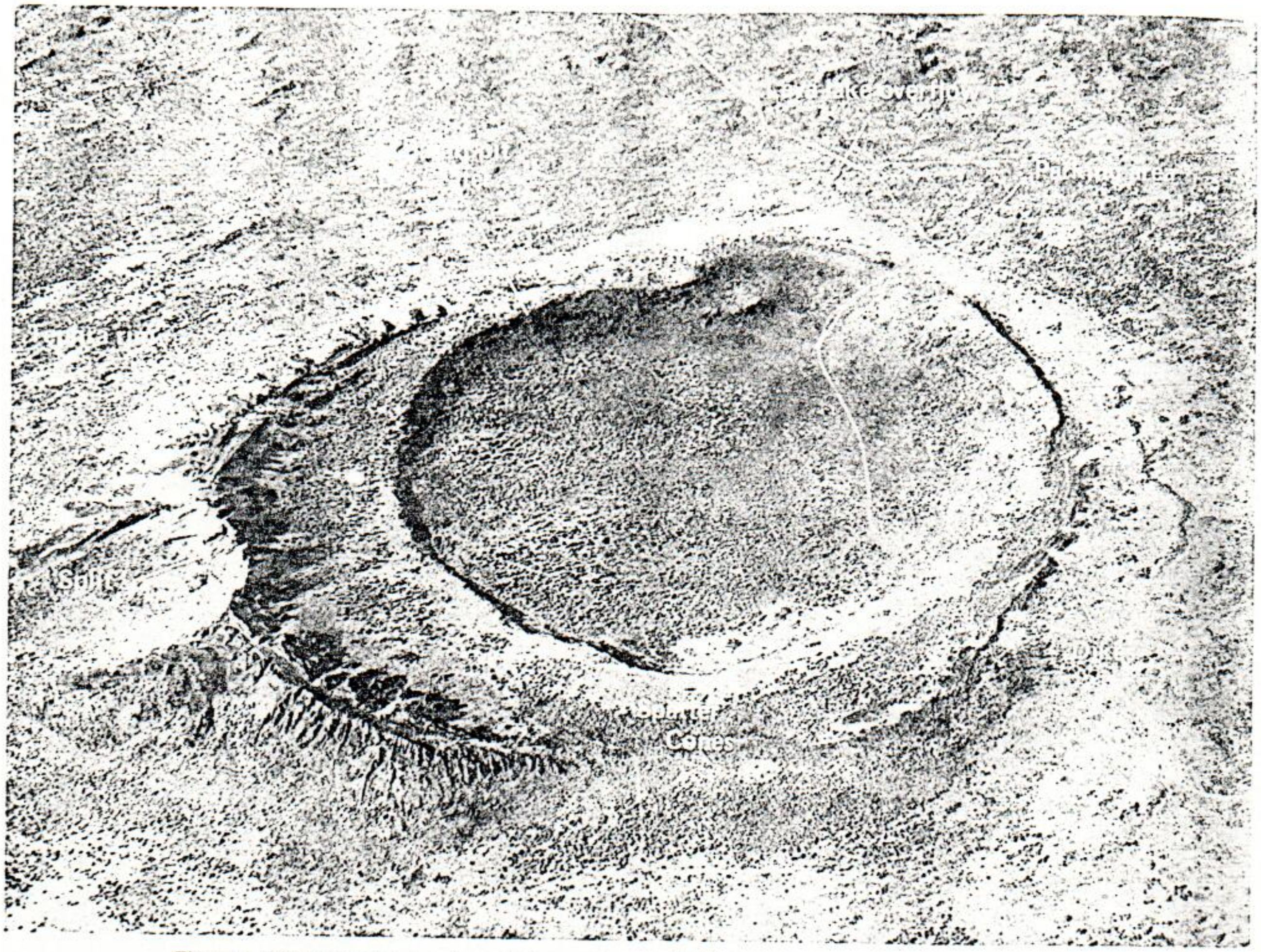

Figure 2. Oblique aerial view toward the southwest of Split Butte. Photograph by Ronald Greeley.

beds and the ring diameter. A topographic notch or erosional "split" approximately 150 meters wide occurs in the thick eastern ash accumulation (Figure 2).

The tephra ranges in color from reddish brown to olive green to black. Basal layers tend to be massive, fine grained, poorly sorted, and extensively palagonitized. Above the basal zone lie thin planar beds of coarser and better sorted ash. Palagonitization and oxidation are less prevalent in these upper layers, which constitute the bulk of the deposits. Beds range in thickness from 2 to 10 centimeters in the upper zone and from a few tens of centimeters to over a meter in the lower zone. Accidental basaltic fragments are abundant and range in size from granules to 1.25 meter-sized blocks. In many places blocks are visible in outcrop with bedding sags in the ash layers below (Figure 4). The layers thin plastically below the blocks and thicken beside them; fracturing of layers is not evident. Lithic fragments are most abundant in the basal tephra layers. The tephra is composed of dense clasts and scoriaceous grains of partially palagonitized sideromelane and a matrix of very finely divided volcanic ash. Scoria grains are found in only a few places in the basal tephra but are the dominant component of the upper, well-bedded layers. The tephra also contains from 3 to 5 percent volume primary plagioclase and olivine crystals, and secondary calcite is locally abundant in palagonitized samples.

A central lava lake was retained by the tephra ring and is in disconformable contact with the tephra (Figure 5; Greeley and King, 1975). Minor lake overflow occurred on the low southwest section of the ring. The lava lake margin is preserved as a narrow circular shelf of basalt, but the central portion has subsided to form a pit crater 20 meters deep and 420 meters across. Two low mounds of spatter occur along the pit crater scarp. The spatter consists of highly oxidized scoria and may represent a degassing outlet for postsubsidence liquids.

Four en echelon basalt dikes intruded the tephra on the northwest section of the ring (Figures 2 and 3).

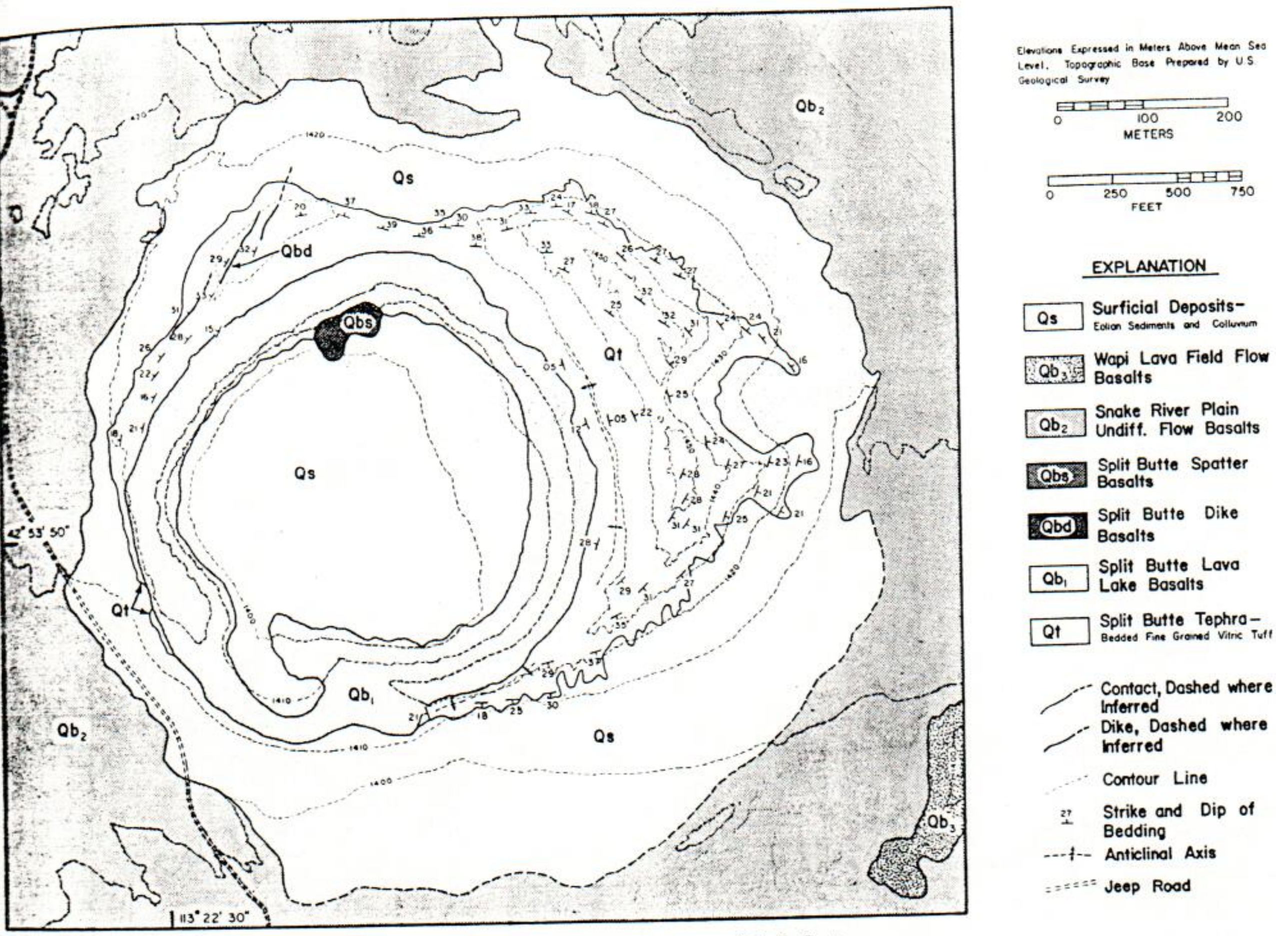

Figure 3. Geologic sketch map of Split Butte.

The nearly vertical dikes are 20 to 30 centimeters thick and have baked tephra along the contacts. They trend tangentially to the ring and can be traced for over 250 meters before disappearing below colluvium.

GENESIS OF SPLIT BUTTE

From field observations and laboratory studies of the ash, we consider Split Butte to be a tuff ring or maar resulting from the interaction of basaltic magma and ground water, followed by an effusive phase of eruption (Figure 6). The ash consists primarily of clear, light brown sideromelane clasts that are locally palagonitized, indicating rapid quenching in a water-rich environment (Fisher and Waters, 1970; Heiken, 1971; Walker and Croasdale, 1971; Macdonald, 1972). The clasts typically are blocky and angular and have few vesicles (Figure 7a), which are small (less than 0.5 millimeter) and spherical. Both the clast shape (Walker and Croasdale, 1971) and arrested vesicle growth (Heiken, 1971) are evidence of quenching by water. Accretionary lapilli are abundant in the tephra and typically consist of a glassy or lithic nucleus coated with an irregular or incomplete layer of fine ash (Figure 7b). Though accretionary lapilli may form by other means, their presence generally indicates the presence of a moist ash cloud during their deposition (Stearns, 1925; Moore and Peck, 1962).

Other evidence for a phreatomagmatic origin are (1) the plastic deformation of ash layers under ejecta blocks (Heiken, 1971; Figure 4); (2) the presence of abundant secondary minerals, calcite, and zeolite in the ash; and (3) the general lack of cinder cone pyroclastics, in particular glass shards as described by Macdonald (1972) and Walker and Croasdale (1971).

Grain size analyses of the tephra also indicate a phreatic origin for the tuff ring. Plots of median diameter versus sorting reveal that phreatomagmatic (Surtseyan) and cinder cone (Strombolian) pyroclastics fall in different fields (Figure 8). Split Butte samples fall mostly within the Surtseyan field, with some extension into the Strombolian field. Separation

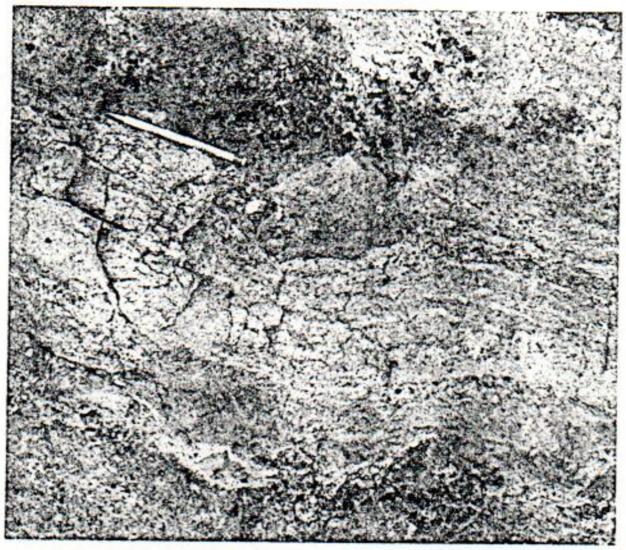

Figure 4. Plastic bedding sag in tephra layers under ejecta block approximately 10 centimeters in diameter. Outcrop face is approximately tangential to tephra ring.

Figure 5. Disconformable contact between massive basalts of the lava lake on the left and uniformly dipping planar beds of tephra on the right.

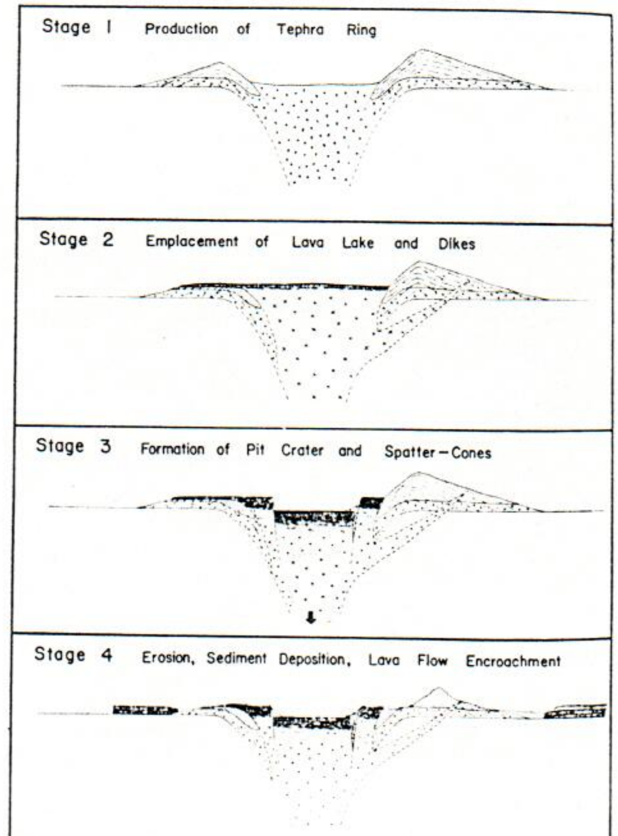

Figure 6. Sequence of events that formed Split Butte (modified from Greeley and King, 1975).

of the samples into massive and bedded deposits shows that massive beds plot within the phreatic field and that the bedded deposits fall in both fields (Figure 9). This and the observations discussed above suggest that the basal tephra resulted from the interaction of magma and abundant ground water. This early phase was followed by a transitional period represented by the sequence of interlayered tephras, during which the degree of magma-water interaction varied sporadically. Finally, interaction stabilized at a decreased level and the planar beds of locally scoria-rich ash were produced.

A change in eruption from explosive to effusive activity led to the emplacement of the central lava lake. This shift in activity is a common feature of tuff rings (Lorenz and others, 1971) and results from a cessation of magma-water interaction. Cessation of the interaction may have resulted from the consumption of ground-water supplies, the removal of access of water to the vent, or an increased eruption rate of magma. Although the lava lake was relatively quiet, as evidenced by the lack of spatter, motion within the lake was sufficient to erode most of the inward-dipping tephra. The slumping of ash into the lava lake caused the disconformable contact visible between the lake basalts and thick tephra deposits in the east. Conformable contacts are prevalent along the low tephra deposits in the west.

Subsequent to partial solidification of the lava lake, the removal of support formed the central pit crater. Though the floor of the crater is largely sediment covered, its horizontal and undisrupted nature argue against a catastrophic collapse. Two mounds of spatter on the ring fracture appear to represent the last volcanic activity at Split Butte.

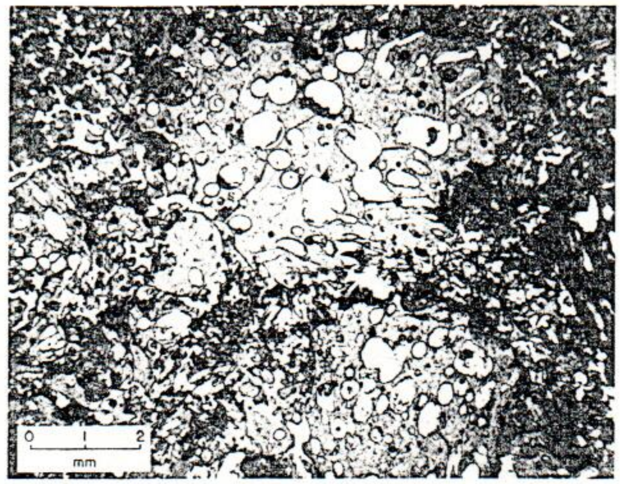

Figure 7a. Photomicrograph of Split Butte tephra under plane-polarized light. Two large vesicular sideromelane grains lie in a matrix of blocky dense clasts, irregular shards, and finely comminuted volcanic dust.

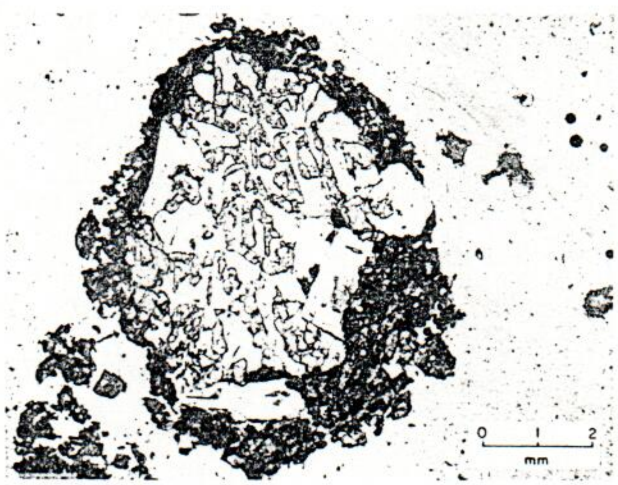

Figure 7b. Photomicrograph of accretionary lapillus in Split Butte tephra under plane-polarized light. Lapillus consists of a lithic clast nucleus approximately 4 millimeters in diameter with a discontinuous and irregular shell of small glass clasts and dust.

SAND BUTTE

Sand Butte lies about 38 kilometers southwest of Craters of the Moon National Monument (Figure 1). It consists of a tuff cone containing a lava lake and is astride a north-south fissure 5 kilometers long (Figure 10). The fissure is a depression 5 to 8 meters deep and 60 to 125 meters wide (Figure 11). Flow units from the fissure typically are 5 to 10 centimeters thick and dip away from the fissure about 5 degrees; dip decreases to 1 to 2 degrees about 100 meters from the vent area. Activity was concentrated locally along the fissure, as indicated by accumulations of spatter. A well-developed lava tube near the southern end of the fissure represents an area of particularly active outflow. The tube is 2 meters wide by 1.4 meters high at the fissure and more than 60 meters long.

The tuff cone is 1.2 kilometers across and 80 meters high and consists of palagonitized vitric ash and abundant lithic fragments. The tephra ranges in color from buff to deep brownish maroon and is typically poorly bedded. Beds range in thickness from 2 to 3 centimeters for a few planar beds to over 2 meters for massive layers. Beds are defined by changes in the grain size, color, and composition of constituent materials; contacts range from gradational to sharp; thin stringers of coarser lithic and juvenile material are seen in many places within beds. Poorly developed cross-bedding of thin laminae is locally present. The beds are typically planar and continuous for tens of meters; dune forms are not visible. The

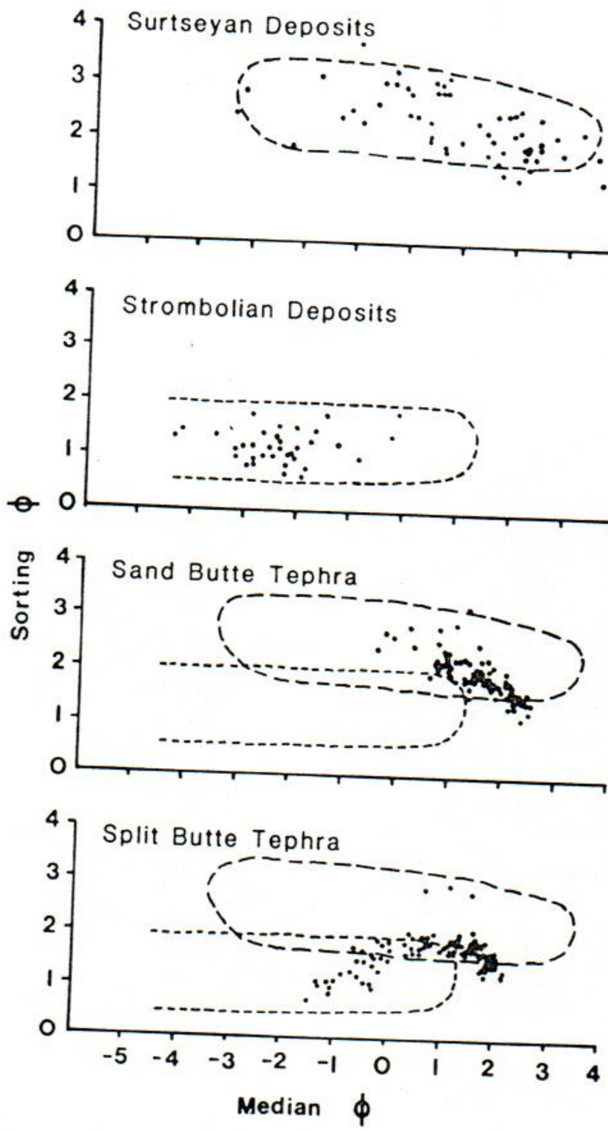

Figure 8. Plots of median diameter versus sorting in ϕ units (ϕ = $-\log_2$ particle diameter) for grain size analyses of Strombolian and Surtseyan near vent deposits of Walker and Croasdale (1971) and Sand Butte and Split Butte tephras. The median diameter represents the ϕ value at which the cumulative frequency curve crosses the 50 percent point. The deviation $\sigma\phi$ is defined as $\phi84 - \phi16/2$ where $\phi84$ is the ϕ value at which the cumulative frequency curve crosses the 84 percent point and $\phi16$ is the value at the 16 percent point. Field outlined by short dashes is the Strombolian Field of Walker and Croasdale (1971), and the field outlined by long dashes is the Surtseyan Field.

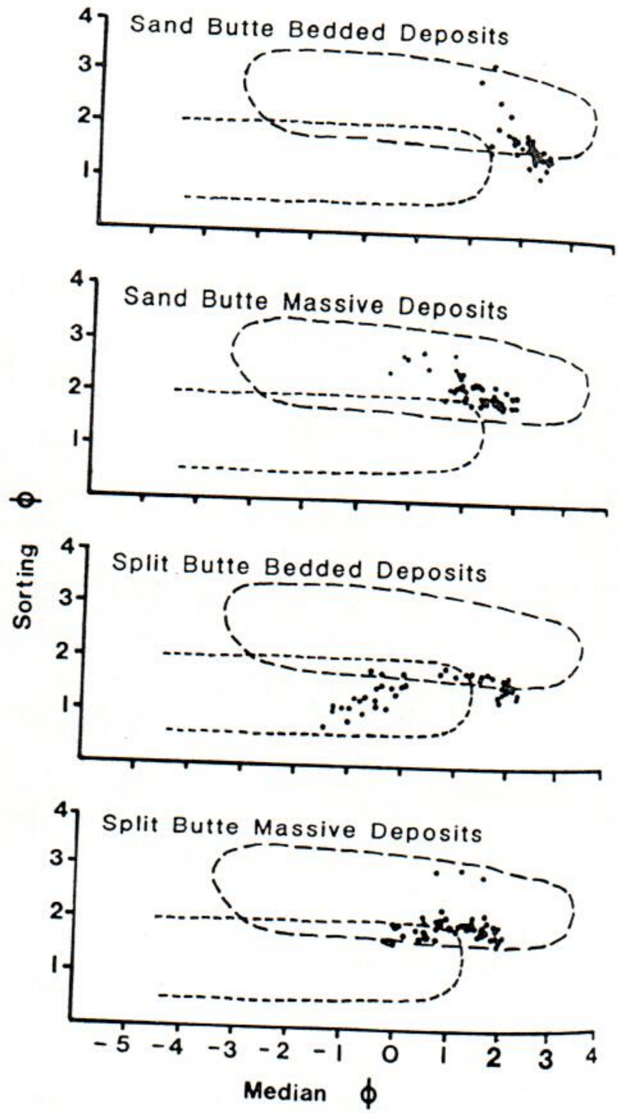

Figure 9. Plots of median diameter versus sorting in ϕ units for massive and bedded deposits of Sand Butte and Split Butte. Dashed outlines are explained in Figure 8.

tephra dips radially outward from 10 to 30 degrees; inward dipping layers are not visible. Lithic ejecta blocks are very abundant throughout the tephra sequence but are slightly more common in the massive ash layers. They consist entirely of basalt and range in size from small granules to 1 meter-sized blocks. Most are angular, although many of the larger blocks (over 40 centimeters) were apparently rounded before emplacement. These larger blocks caused many plastic impact sags in the ash layers below (Figure 12). Slightly coarser fill occurs in front of and behind blocks, and thinning of ash layers over blocks is visible.

The tephra consists of moderately to heavily palagonitized sideromelane clasts and vesicular grains, olivine and plagioclase crystal fragments, and lithic inclusions in a matrix of very fine ash (Figure 13a, b). The clasts are the dominant component and have angular shapes. They tend to be dense, with relatively few vesicles that are small and spherical where present. Vesicular grains are ovoid to irregular and scoriaceous, with numerous stretched and deformed vesicles (Figure 13a); they are locally concentrated in thin (less than 2 millimeters) layers but are subordinate to the smaller clasts. Samples of bedded tephra consistently contain a greater proportion of vesicular grains than do massive layers. Secondary calcite and zeolite are locally abundant in the heavily palagonitized samples.

Sand Butte displays only minor assymmetry, with slightly more voluminous deposits on the eastern flank, evidently the result of prevailing winds. The ring is slightly elongate in a north-south direction, due to vent geometry. Two notches occur in the tephra ring where it intersects the trace of the underlying fissure. The southern notch lowers the rim by some 15 meters, whereas the cone is completely breached on the north. Both notches resulted from the erosion of tephra by effusive activity along the fissure, though activity was more vigorous in the north. This is indicated by the depth of the north gap and the presence of spatter high in the walls of the notch, derived from a north-south striking dike exposed in the west wall of the notch, 15 meters below the tephra rim.

The cone retained a central lava lake that subsequently subsided to form a shallow pit crater. The original lava level is preserved as a discontinuous scarp of massive basalt in contact with the inner tephra walls (Figure 14). Colluvium discontinuously mantles the lava lake surface, which exhibits the swirling pattern of pahoehoe ropes typical of some Hawaiian lava lake activity. The lava lake and fissure basalts are very similar compositionally but display wide variation in texture. Olivine is the only phenocryst phase present in the fissure flows; plagioclase is present as unoriented groundmass laths that are typically 0.5 millimeter long. Lava lake basalts are coarsely crystalline with both plagioclase and olivine phenocrysts present. At the contact of lake basalts with tephra, however, phenocrysts of embayed olivine lie in a fine-grained matrix of flow-oriented plagioclase microlites and subophitic clinopyroxene crystals.

A moatlike depression approximately 5 meters deep encircling Sand Butte was formed by the encroachment onto the Butte of a lava flow of the Snake River Group (Figure 11). This lava flow also entered the south channel, which it partly filled, and the north channel where only a minor lobe of the flow is visible.

GENESIS OF SAND BUTTE

Sand Butte is a tuff cone formed by the phreatomagmatic interaction of ground water and basaltic magma. Evidence for this conclusion is the same as that presented for Split Butte. The tephra is dominantly palagonitized sideromelane that shows textural evidence of rapid chilling (Figure 13). Accretionary lapilli, occasionally without nucleii, are abundant in the tephra. Field evidence for phreatomagmatic activity includes the plastic deformation in impact sags, the abundance of ejecta blocks, and the paucity of scoria in the tuff beds.

Pyroclastic flow was apparently the dominant depositional mechanism at Sand Butte, based on several lines of evidence. First, the large-wavelength undulatory nature of the rim is characteristic of tuff rings where flow has been active (K. Wohletz, personal communication). Although radial exposures of the tuff are poorly developed, some cross-bedding in the ash is locally visible. Tephra layers overlying basalt ejecta blocks thin visibly over the blocks, and air-fall "drapes" are not evident. In addition, ash fill behind impact blocks is coarser than in surrounding beds. Bedding sags under ejecta blocks, however, indicate the presence of some air-fall activity.

We conclude that Sand Butte tephra is mostly phreatic and that pyroclastic flow was the dominant depositional mechanism, forming most of the poorly bedded to massive layers. Air-fall activity was minor, and these deposits are limited to the thinly bedded layers. Although tephra production and effusion of fissure lavas may have overlapped, we consider the phreatic phase of the eruption to have ended essentially before most of the basalt was erupted. The relationship between fissure activity and tephra is clearly evident in the west wall of the north gap, where tongues of spatter disconformably overlie the tephra. These spatter deposits have run down the tephra slope and originated from a possible basalt

Figure 10. Oblique aerial view of Sand Butte. Photograph by Ronald Greeley.

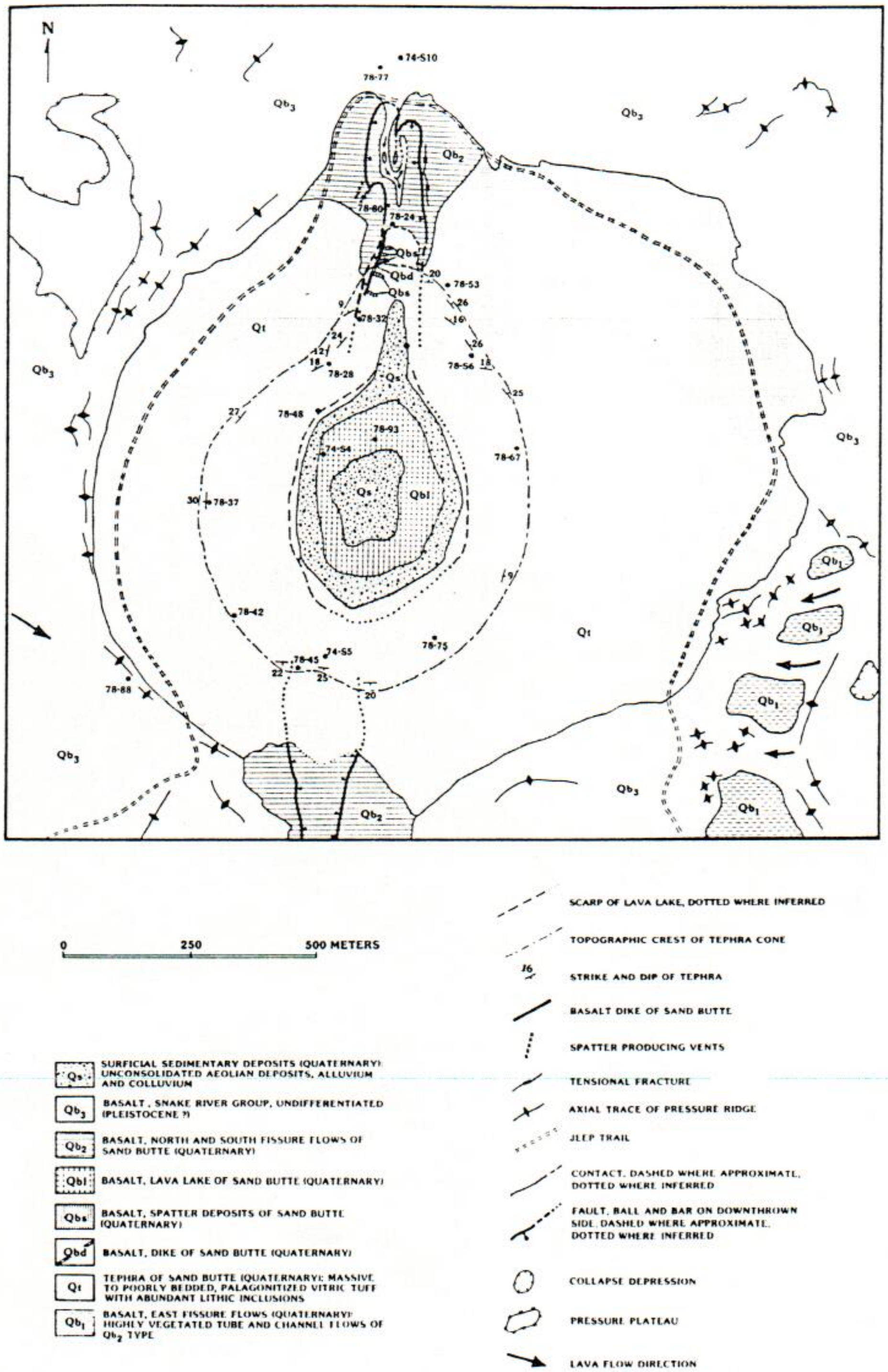

Figure 11. Geologic sketch map of Sand Butte.

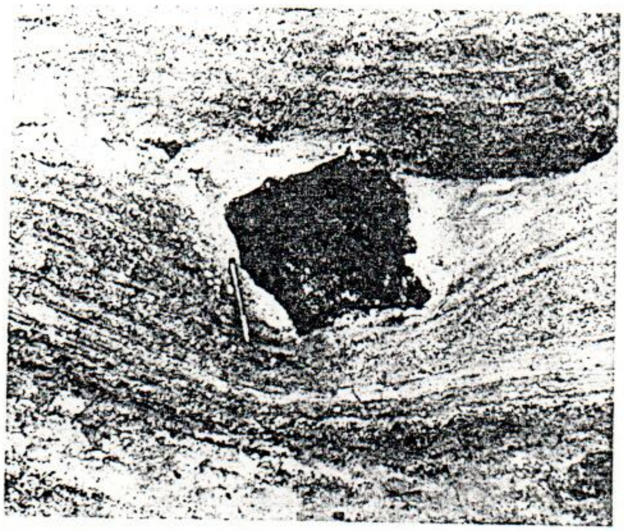

Figure 12. Impact block approximately 23 centimeters across with characteristic asymmetric sag in tephra layers below. Center of crater is to left. Note shadow zones on front of and behind block.

dike (Figure 11). The possible dike consists of a curviplanar sheet of lava, striking north-south and dipping 60 to 70 degrees east, that crops out high in the gap wall. The emplacement of the lava lake postdated the formation of the north gap, as indicated by the lake scarp following the topographic contours of the north gap area (Figure 11). The lake apparently never rose high enough to flow through the north gap area.

COMPARISON OF SPLIT AND SAND BUTTES

Both features consist of subcircular tephra deposits with a central crater 500 to 600 meters in diameter. Both involved an early phase of phreatomagmatic activity, followed by an effusive phase that resulted in the emplacement of a lava lake; both lakes subsided to form shallow pit craters. There are differences, however, in eruptive and depositional processes that are reflected in their morphology and in the tephra. Sand Butte is nearly symmetrical, whereas Split Butte is strongly asymmetrical, with much thicker ash deposits on the downwind side of the vent. We consider this evidence that Split Butte formed while strong westerly winds were active and that Sand Butte formed during a relatively calm period. Split Butte may be best described as a tuff ring, whereas the more voluminous deposits of Sand Butte form a tuff cone. Although the height-width ratio at Split Butte may be as great as 1:12 for the thickest ash deposits, the average height-width ratio is much lower, probably in the range of 1:25 to 1:30. The height-width ratio of Sand Butte is a relatively uniform 1:15. Heiken (1971) has suggested that the differences in height-width ratios of cinder cones and tuff rings and cones are partly dependent upon the depth of water-magma interaction, with deeper interaction resulting in higher constructs. The ash layers of Split Butte display a transition from massive and poorly bedded to planar beds in the upper sequence. Tephra at Sand Butte displays no such transition; beds are poorly bedded to massive throughout the sequence with only few planar beds visible. These planar beds have grain size distributions indicative of air-fall deposition and represent the lower energy regime of a base surge explosion.

The tephra displays compositional differences as

Figure 13. Photomicrographs of Sand Butte tephra under plane-polarized light: (A) a large accretionary lapillus in a matrix of blocky to irregular clasts and fine dust. The core of the lapillus consists of a grain of vesicular and plastically deformed sideromelane. (B) a phenocryst of olivine that was embayed along a probable magnesium-rich zone by magmatic liquid that was quenched to form sideromelane.